Study of Exotic Baryons in Photoproduction off Protons

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Abstract

We propose to conduct a systematic, high statistics study of the $\Theta^+(1540)$, and search for the exotic $\Xi^{--}(1860)$ state on protons, using the CLAS detector and the energy-tagged photon beam in Hall B. The proposal contains two parts: The first part is aimed at a high statistics study of the Θ^+ on protons, and complements the already approved and scheduled study of the Θ^+ on neutrons (deuterium). We propose to further explore the possible evidence of an excited state of the $\Theta^+(1540)$ with a mass of 40 - 50 MeV above the Θ^+. For this part we require an electron beam energy from 3 to 4 GeV. The second part is aimed at the exploration of reaction mechanisms for the production of the Θ^+, and the search for the predicted exotic Ξ^{--}, for which evidence has been seen in experiment NA49 at CERN. This part requires an electron beam with an energy of at least 5.7 GeV. Both parts of the proposal require an upgrade of the CLAS start counter, a detector used for photon induced reactions.

Overview:

The following overview pertains to the following two proposals:

"Spectroscopy of Exotic Baryons with CLAS: Search for Ground and First Excited States"

"A Comprehensive Study of Exotic Baryons with CLAS off of a Proton Target"

Both proposals involve the same collaboration and all members are committed to carry through both. We stress that both proposals are aspects of a coherent collaboration wide effort of discovery, verification, and characterization.

Physics overview:

The search for evidence of baryon states that require a minimum of five quarks, or so called penta-quarks, has become a focus and high priority for hadronic physics. Evidence for the $\Theta^+(1540)$, a strangeness $+1$ baryon that has been observed in a mass range from 1530 to 1550 MeV in six independent experiments, is already fairly strong. However, many questions regarding the Θ^+ remain.

- The mass of the Θ^+ is not fully consistent between the various measurements, and requires higher statistics to allow checks of systematic dependencies.
- The question of kinematical reflections that could distort or generate peaks in the mass distributions needs to be addressed more fully.
- A preliminary analysis of the channel $\gamma p \to K^0 K^+ n$ and $\gamma p \to K^\circ K^\circ p$ reveals evidence for a second state 40 - 50 MeV apart from the Θ^+. Such a state is expected in some models. Much higher statistics will be needed to refute or confirm such a state.
- The spin of the Θ^+ is still unknown, and the preference for isospin 0 needs to be confirmed and settled.
- The important question of the parity of the state may only be settled through measurements in different channels.

The first proposal seeks to address these questions by collecting an order of magnitude more data than have been obtained in previous measurements. The beam energy will be 4 GeV, and will allow excellent mass resolution for narrow states. This is crucial for separating signal and background. Together with the measurement on the neutron, this will establish a benchmark data set for the study of S=+1 exotic baryons in the mass region $M(NK) < 1.8$ GeV.

Higher energies are needed to address a variety of other questions:

- The production mechanism for the Θ^+ is basically unknown. There are indications that intermediate excited nucleon resonances may play an important role at higher energy.
- New results from CERN experiment NA49 show evidence for another exotic baryon, a doubly negative strangeness -2 Ξ^{--} at 1862 MeV. Existence of such a state was predicted within models that also predicted the Θ^+. The NA49 results are currently the only ones showing evidence for such a state. This must be confirmed.
- Other, non-exotic, 5-quark states, such as Ξ_5^- and Ξ_5°, and three Σ_5 states, as well as two nucleon states N_5° and N_5^+ are also predicted within these models. These states are not expected to be narrow, and may require a significant amount of data to be identified. However, their masses should be well constrained by the $\Theta^+(1540)$ and the $\Xi^{--}(1860)$.

To address these questions efficiently, the highest available beam energy, at least 5.75 GeV, and the highest possible statistics are needed. This will establish a benchmark data set for the study of 5-quark states using an energy-tagged photon beam that allows employing the missing mass technique.

We submit these two proposals under the same overview as they reflect a CLAS collaboration effort and priority, and express a long-term commitment to a "second generation" program for the study of 5-quark states. The question of the existence of two states is the most urgent one we want to address with the first proposal, for which we request 25 days of beam time at an energy of 4 GeV. The Production mechanism and properties of the Θ^+ and the search for, and study of, Ξ_5 states will be addressed in the other proposal. This requires 40 days of beam time at an energy of at least 5.75 GeV or higher. Once again we stress that both are aspects of a coherent collaboration wide program.

Addendum to
A Comprehensive Study of Exotic Baryons with CLAS off of a Proton Target

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1 The Study of the $N^*/\Delta^*(2400)$

Important new results have become known to us after the submission of our proposal on December 9, 2003. In our recent publication on the observation of the Θ^+ [1] we suggested that the experimental evidence supported the existence of a higher mass N^* or Δ^* state with anomalous narrow width, and mass of about 2400 MeV/c^2. Recently the NA49 collaboration has corroborated our scant evidence for this state [2].

The existence of this narrow state, which decays into a manifestly exotic baryon, the Θ^+, suggests that there may exist a heretofore undiscovered new class of hadronic matter which is in some way related to pentaquark baryons. Currently we can only speculate about the narrow widths of both the $N^*/\Delta^*(2400)$ as well as the $\Theta^+(1530)$. In any event, there is now new interesting baryon spectroscopy that spans the mass range 1530 MeV/c^2 to at least 2400 MeV/c^2.

The Cebaf Large Acceptance Spectrometer (CLAS) at the Jefferson Laboratory has taken a preeminent position in studying this new form of hadronic matter, and we feel that our current proposal is uniquely positioned to expand this investigation. For one, we run at the highest energy available at Jefferson Laboratory and with the broadest energy range, which allows access to the observed high mass state and the Θ^+, as well as any intermediate mass states which may exist. While in the Ξ sector we are most sensitive to the Ξ^{*-}, which is not manifestly exotic, our high sensitivity will be able to quickly corroborate other observations which may have very weak and, on their own, inconclusive signals, such as that as observed at NA49 [3]. Our broad energy range will allow the excitation of new hadronic matter in both formation and production processes. The large acceptance of CLAS allows sufficient access to the multi-particle final states which result.

It appears that we have uncovered a new form of hadronic chemistry, which will supply crucial information to unravel the non-perturbative nature of Quantum Chromodynamics. We feel that our proposal is superbly matched to continue this study.

References

[1] V. Kubarovsky et al., e-Print Archive: hep-ex/0311046, submitted to PRL.

[2] NA49 collaboration, D. Barna and F. Sikler, http://na49info.cern.ch/cgi-bin/wwwd-util/NA49/FILE?/ftp/NA49/Notes/Physics/thetaplus-bp.pdf.

[3] NA49 collaboration, C. Alt et al., e-Print Archive: hep-ex/0310014.